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Superconducting MEM switches for microwave power applications

Final technical report

Award number F49620-02-1-0044

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Organization: Florida International University

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FINAL PROGRESS

- In the fourth year of the project the work on optimization of fabrication process for a capacitively shunted RF micro-electromechanical superconducting switch was continued.
- Simulations and measurements show that the filter response is not critically distorted by the presence of the MEM switches.
- When the filter is not active, the signal is attenuated by a value of <0.9 dB at 3 GHz.
- Yield of fabricated devices was improved to be greater than 40%.
- Work on study of the effect of temperature on the Au Young's elastic modulus was performed.

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Project title:	"Superconducting MEM switches for microwave power applications."
Organization:	Florida International University
P.I.	Vlasov, Yuri
Co-P.I.	Larkins, Grover
Award No.	F49620-02-1-0044
Project period:	from 11/15/2001 to 11/14/2005
Total project cost:	$394,635.00
Program manager:	Dr. Harold Weinstock

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- Jose Martinez

FIU undergraduate student:
- James Burke

Demographics:

	African American	Hispanic	Asian	Women	Other	Total
Faculty/Staff				1	2	3
PhD students					2	2
Graduate students	3	2				5
Undergraduate students	1					1
Total	4	2	0	1	4	11
Percentage of total	36%	18%	0%	9%	36%	

2001 – 2002 year summary

- The work performed in the first year of the project proved that $YBa_2Cu_3O_7$ is a good candidate for use in MEMS applications.
- The fabricated switches showed good microwave characteristics at cryogenic temperatures which are in line with those in the simulations.
- Isolation of more than 34 dB below resonance and an insertion loss of less 0.05 dB at 0.5 GHz was shown.
- There were issues with stiction and high actuation voltage (from 75 V to 120 V) which need solving and on which work was planned to be done.

2002 – 2003 year summary

- MEM switches have been incorporated in three different high- Tc superconducting resonators.
- Insertion loss has been shown to be less than 0.007 dB.
- Yield has been improved to ~5%, but issues still remain.
- Actuation voltage in our devices has stabilized at about 75 V.

2003 – 2004 year summary

- MEM switches have been incorporated in five different high- T_c superconducting devices.
- The coplanar shunt switch isolation was > 34 dB below resonance.
- Insertion loss of shunt switch has been shown to be < 0.007 dB.
- Yield of fabricated devices was improved (25%) due to optimization of fabrication process.
- A superconducting switchable bandpass filter has been successfully designed and simulated.
- Several different prototypes of switchable filter have been fabricated.

2004 – 2005 year summary

- In the fourth year of the project the work on optimization of fabrication process for a capacitively shunted RF micro-electromechanical superconducting switch was continued.
- Simulations and measurements show that the filter response is not critically distorted by the presence of the MEM switches.
- When the filter is not active, the signal is attenuated by a value of < 0.9 dB at 3 GHz.
- Yield of fabricated devices was improved to be greater than 40%.
- Work on study of the effect of temperature on the Au Young's elastic modulus was performed.

A. Concept and fabrication of the first MEM switch on superconducting transmission line

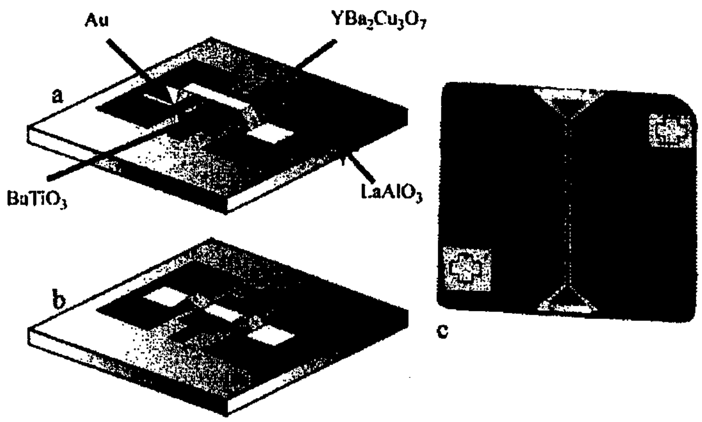

Figure 1.
Schematic of cross section of the switch in (a) "up" and (b) "down" positions.
The first fabricated MEM switch on superconducting transmission line (c).

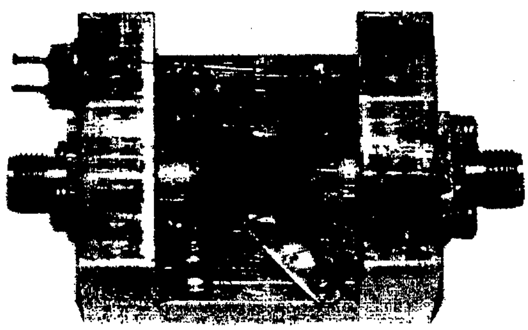

Figure 2.
MEM switch in test fixture

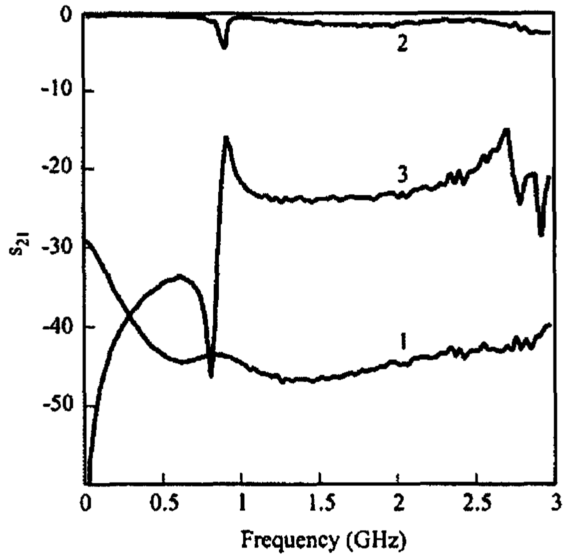

Figure 3.

s_{21} of coplanar waveguide with MEM switch:
(1) – T = 300 K, switch is in "up" position; (2) – T = 14 K, switch is in "up" position, insertion loss at 0.5 GHz is less than 0.05 dB; (3) – T = 14 K, switch is in "down" position.

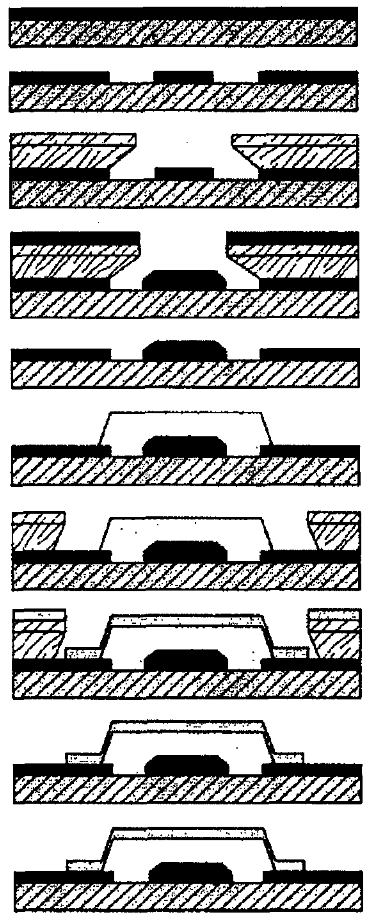

Figure 4.

Steps of optimized fabrication process of MEM switch integrated in superconducting microwave device.

(a) The substrate receives YBa2Cu3O7 film deposited in PLD system.
(b) Photoresist is spun, patterned, and developed using the transmission line mask.
(c) The BaTiO3 dielectric patch is fabricated using a liftoff process and RF magnetron sputtering. A dual layer of AZP4620 and AZ5214-E photoresist are spun and developed using the dielectric mask with the underlying layer having been flood expose.
(d) The sample undergoes 3 hours of BaTiO3 on-axis sputtering.
(e) Liftoff of the BaTiO3 is carried out in acetone at 50°C.
(f) The bridge support makes use of a polymer (PMGI SF15) that is spun to a thickness of 3 μm and patterned using the sacrificial layer mask.
(g) Dual layer photoresist system is utilized using the gold bridge mask.
(h) The deposition of gold is carried out using thermal evaporation.
(i) Gold film liftoff in acetone.
(j) The final bridge release uses a wet release process using PMGI stripper (Nano Remover) and critical point CO2 drying.

B. Tapped microstrip "T"-resonator

Fabrication and testing tapped microstrip "T"-resonator allowed us to make more accurate estimation of insertion loss of microelectro mechanical switch.

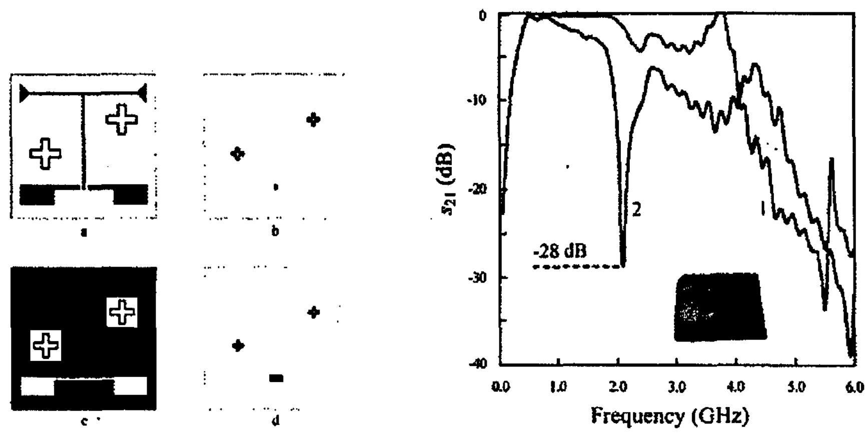

Figure 5.
Left: masks for fabrication of tapped microstrip "T"-resonator with MEM switch.
Right: frequency response of the tapped microstrip "T"-resonator
Curve 1 - measured s_{21} when switch is in "DOWN" state (grounded "T")
Curve 2 – measured s_{21} when switch is in "UP" position (ungrounded "T")
$T = 38$ K, switch actuation voltage $V = 122$ V.

Insertion loss of the MEM switch is estimated to be less than $10\,log(1\text{-}10^{-2.8}) = 0.007$ dB

C. Switched microstrip "T"-resonator

Switched superconducting "T"-resonator showed significant change in frequency response at cryogenic temperature when switching. When membrane of the MEM switch is pulled down by applied electrostatic field produced by pull-down voltage applied, the resonant frequency changes by approx. 20%.

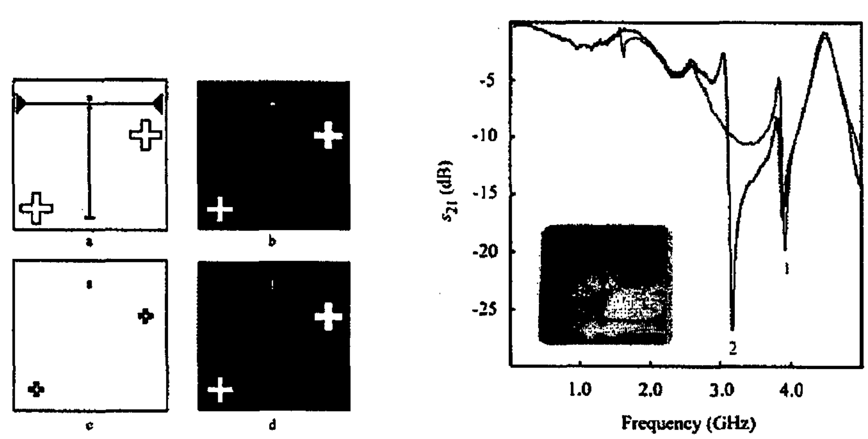

Figure 6.
Left: masks for fabrication of switched "T"-resonator with MEM switch.

Right: frequency response of "T"-resonator (1) when switch is in "UP" position and (2) when it was actuated with $V = 150$ V.

D. Coplanar "T"-resonator

Microwave tests of coplanar "T"-resonator showed few surface modes in frequency response. Switching between resonance at 2 GHz and 4 GHz is in agreement with simulated data.

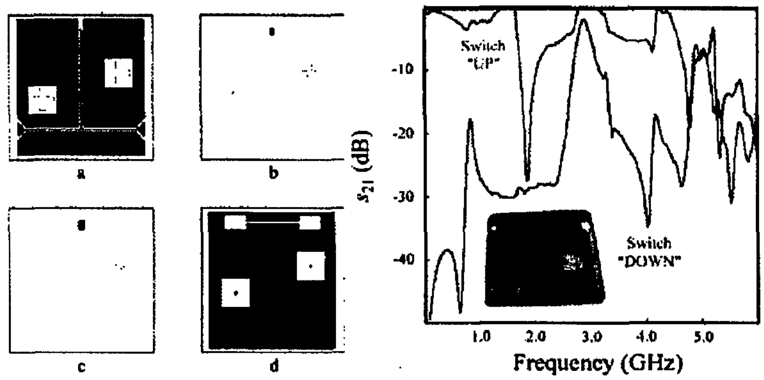

Figure 7.
Left: masks for fabrication of coplanar "T"-resonator with MEM switch.
Right: frequency response of coplanar "T"-resonator.
$T = 30$ K. Pull-down voltage $V = 150$ V

E. Switched filter

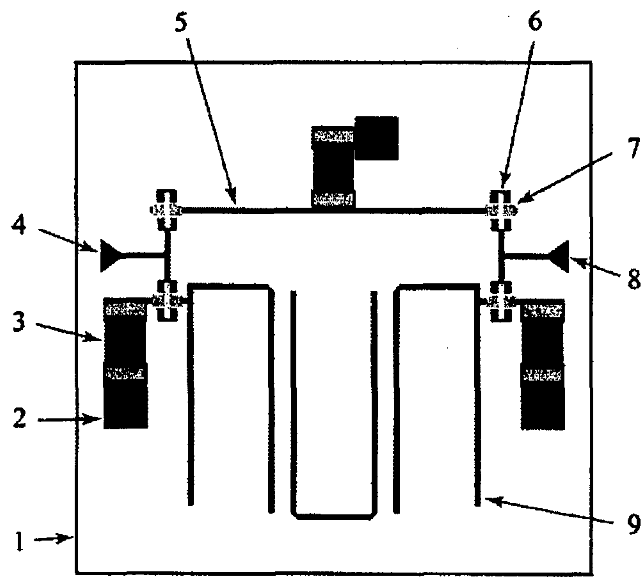

Figure 8.

Outline of superconducting bandpass filter with integrated series MEM switches. 1 – 15 mm x 15 mm $LaAlO_3$ substrate; 2 – DC bias contact pad; 3 – resistor; 4,8 – RF input; 5 – $YBa_2Cu_3O_7$ throughline; 6 – suspended gold bridge; 7 – $BaTiO_3$ patch; 9 - three pole bandpass filter.

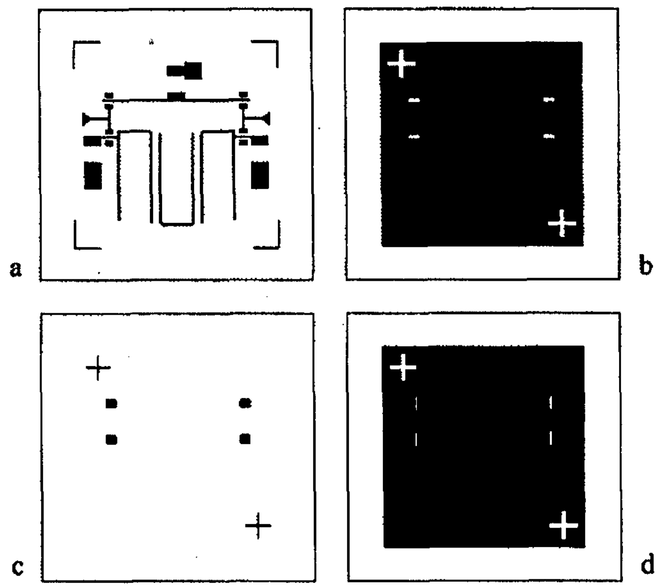

Figure 9.
Masks for switched filter fabrication. (a) $YBa_2Cu_3O_7$; (b) $BaTiO_3$; (c) PMGI sacrificial layer; (d) Au.

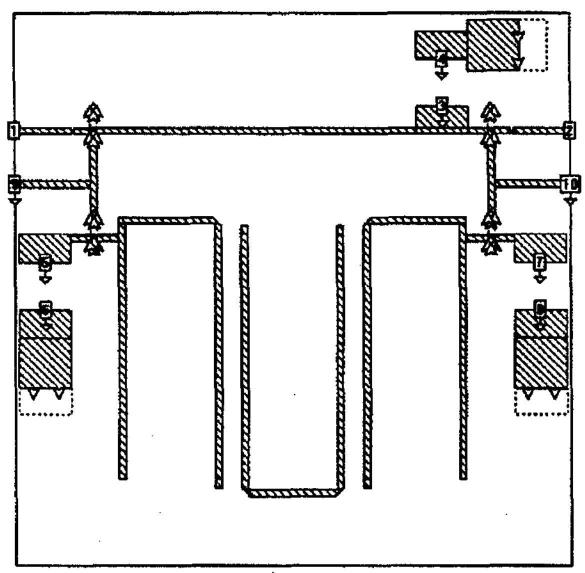

Figure 10.

Sonnet simulation geometry for verification of Q magnitude dependence on resistor value when placed near a switch.

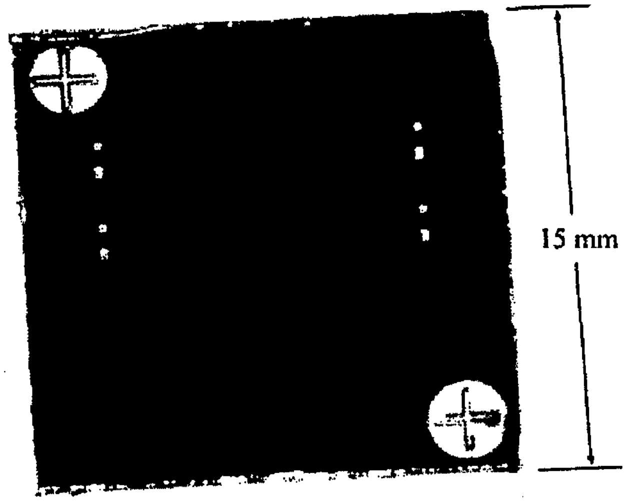

Figure 11.
Photograph of fabricated switched filter

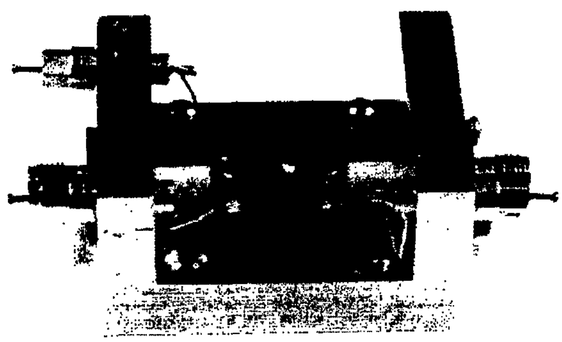

Figure 12.
Fabricated device mounted on test fixture. Notice the three feedthrough capacitors; they provide access to the substrate, so voltage can be applied for switches actuation.

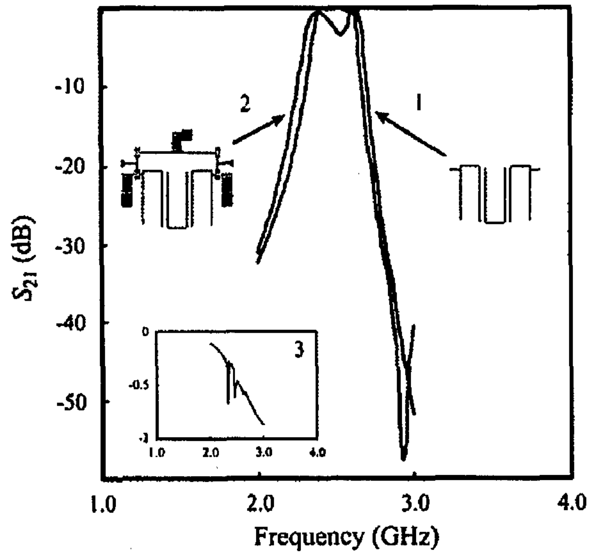

Figure 13.
Simulated frequency response.
(1) filter alone; (2) filter with switches; (3) throughline with switches.

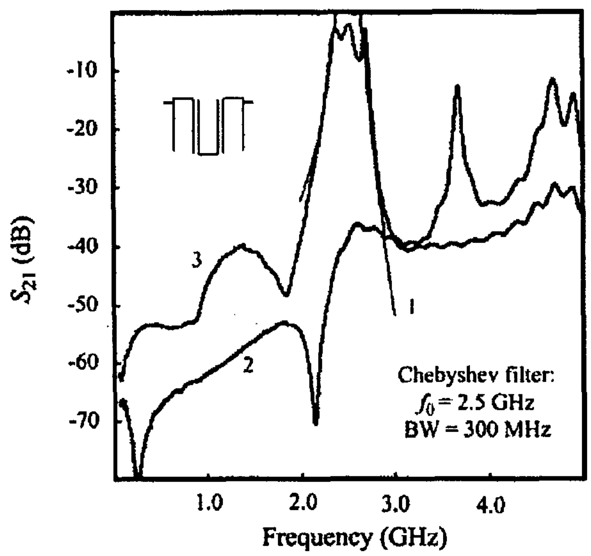

Figure 14.
Filter response. (1) simulated; (2) measured at $T = 300$ K; (3) measured at $T = 17$ K.

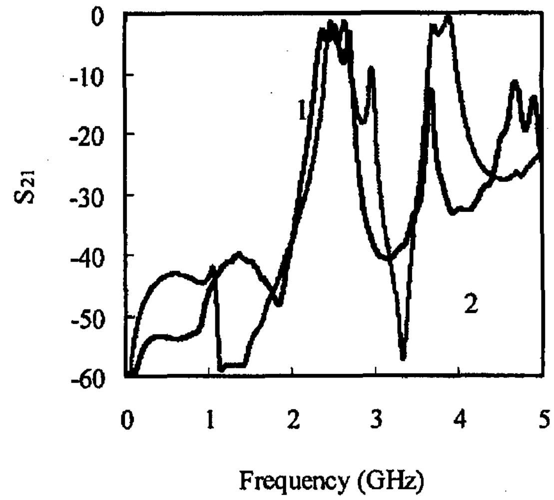

Figure 15.
Measured response at $T = 15$ K: (1) – filter alone; (2) – device with the filter turned on.

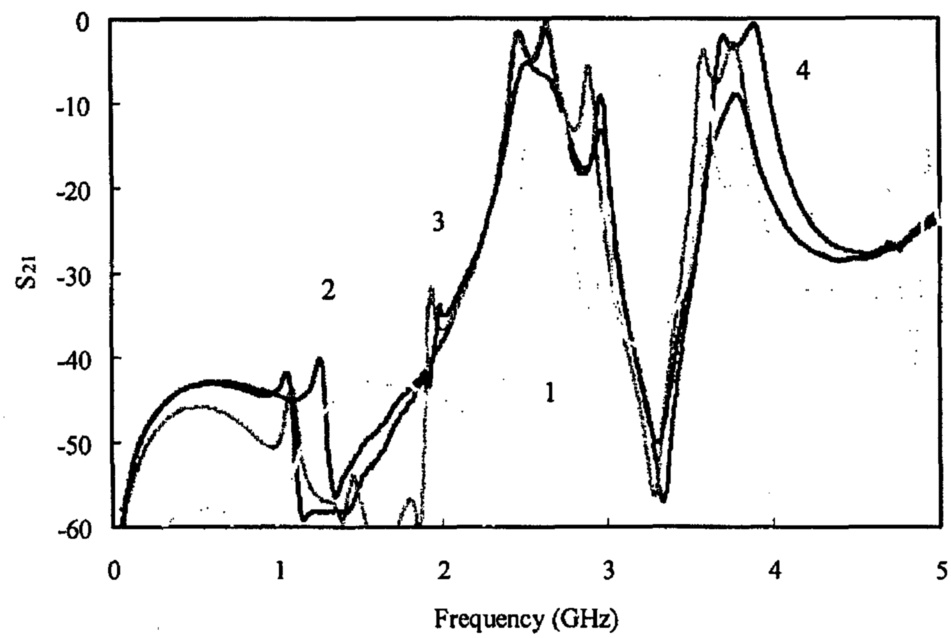

Figure 16.
Measured response at $T = 12$ K: (1) – filter with sputtered $BaTiO_3$ patches; (2) – filter with PLD $BaTiO_3$ patches; (3) – filter without $BaTiO_3$ patches; (4) – filter with PLD $BaTiO_3$ patches and with resistor pads.

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9. Martinez J., Hijazi Y., Noel J., Vlasov Y. and Larkins G. Design, Simulation, and Fabrication of Switchable Superconducting Bandpass Filter With MEM Switches. 6th European Conference on Applied Superconductivity (EUCAS-2003), 14-18 September 2003, Sorrento, Italy, Book of abstracts, p. 65.
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